Towards Laws of the 3D-printable Design Web

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ABSTRACT

This is a preliminary descriptive study of a new form of digital content: 3D-printable designs of physical things. We introduce a new dataset collected from one of the most popular sites for publishing and sharing physical object designs. We describe the data and its properties, and present an interactive visualization to facilitate further exploration of this space.

1. INTRODUCTION

Very recently we have witnessed an explosive growth of 3D printing, and rapid manufacturing at the consumer level in general. Almost every day we see examples of the technology and its application in the news. Even though much of this is still fraught with some hype (such as dreams of Star Trek replicators, or noble but perhaps utopian visions of "democratizing manufacturing"), the fact that 3D printing has substantially lowered barriers to entry in designing and making physical objects is undeniable (as one of the authors himself can attest). Part of the reason is that now objects can be designed and manipulated in a computer. However, like other forms of digital content (e.g., documents, software, music), this is only part of the story: digital representation also enables online sharing and collaboration [2, 3]. A prime example of the potential of all these technologies is the design of consumer-grade 3D printers themselves [1] which, perhaps unsurprisingly, was what many early adopters of the technology used it for.

However, despite hearing about 3D printing daily, very few studies have looked at the digital content of physical things, and the processes that generate it. This work is a first step towards covering this gap.

2. DATA AND OBSERVATIONS

In this work we aim to introduce the overall context and dataset to a broader audience, rather than analyze a single specific aspect of the data; this is beyond the present scope. After a general description of the domain and collected data, we then highlight some initial observations, which we believe are interesting, and perhaps surprising, from a web science perspective.

WebSci'14, June 23–26, 2014, Bloomington, IN, USA.
ACM 10.1145/2615569.2615660.

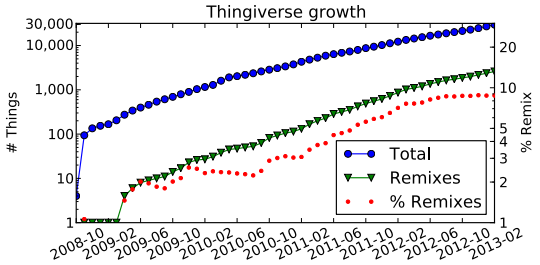

Figure 1: Thingiverse and remix growth (log).

Thingiverse is a site for publishing and sharing physical object designs, which combines aspects of a publishing platform and social network. Although many similar sites have recently appeared, Thingiverse is one of the earliest and by far the most popular, for both the designer and user communities. The data contains 36,504 public things. Although "things" can be anything, the *vast* majority (almost 90%) are designs that can be 3D printed.

The two main entities on Thingiverse are *things* and *users*. Things are *created* by one user (multiple authors are not supported) and has a fixed creation date. Each thing also has text attributes, such as title, description, and, optionally, instructions. The creator has to classify it under one category among a predefined set and may, optionally, add free-form text tags. Finally, each thing typically has a number of files associated with it; 89% of all things have a 3D mesh representation and, out of these, 18% have an algebraic representation as a constructive solid geometry (CSG) expression, typically in the OpenSCAD language.

Users can interact with things in a number of ways, which includes *comments*, *likes*, and *makes* (a stronger form of like, which requires building a thing and uploading one or more photos). Although only creators can add tags, other users can create named *collections* and add things to them.

Finally, creators can indicate that their design *remixes* another thing. This is a directed many-to-many relationship, from a *source* which is remixed into a *derived* thing. The exact semantics of a remix are up to the creator, but the relationship is typically used to indicate some form of creative affinity. The aspect of remixing has been identified in other domains as well, where it often takes a more structured form (typically indicating a direct derivative or "branch"), and has been studied in the context of, e.g., videos [5], music [4], and educational programming language communities [6].

Doubling every six months. Figure 1 shows the total number of things over time (blue) which is growing expo-

Variable	Best predictors	Worst predictors
$\#Views$	$\#Likes$: 43.1–44.6, $\#DLs$: 0.35–0.38, $\overline{\#Views}'$: 0.28–0.31	$\overline{\#Make}'(p = 0.48)$, $\overline{\#Remix}'(p = 0.06)$
$\#D/Ls$	$\#View$: 0.20–0.21, $\#Like$: 8.5–9.8, $\#Make$: 42.0–50.1	$\#Remix(p = 0.66)$, $\overline{\#Remix}'(p = 0.51)$
$\#Likes$	$\#Views$: 0.006, $\#Make$: 2.72–2.83, $\overline{\#Likes}'$: 0.42–0.46	$\overline{\#Remix}'(p = 0.59)$, $\overline{\#DLs}'(p = 0.27)$
$\#Makes$	$\#Likes$: 0.074–0.077, $\#$**Files** : −0.13–0.11, $\overline{\#Makes}'$: 0.28–0.33	$\overline{\#Remix}'(p = 0.99)$, $\overline{\#DLs}'(p = 0.51)$
$\#Remix$	$\#Views$: 0.0003, $\overline{\#\textbf{Remix}}'$: 0.18–0.27, $\#$**Sources** : 0.19–0.39	$\overline{\#\textbf{Make}}'(p = 0.71)$, $\#DLs(p = 0.66)$

Table 1: Best and worst predictors for various features (overbars indicate averages over *other* things by the *same* designer); see text for discussion of highlights.

nentially, with a compound doubling time of 6.1 months! Furthermore, if we consider only remixes (green), then the growth rate far outpaces the overall rate, with a compound doubling time of 4.6 months. Even though remixing is a popular feature of Thingiverse and perhaps unique among similar sites, it is far from the reason of its existence, unlike other sites [4]. Despite this, the growth rate of remixing is impressive and, although bound to abate, there is no evidence that this is happening (red)[1].

Popularity: views vs. likes vs. makes. Table 1 summarizes the results of least-squares regression on measures of user actions. The table shows the top-3 best predictive features ($p < 0.01$, ranked by t-test scores) and 95% confidence intervals of corresponding regression coefficients, as well as the bottom-2 worst features.

The relative incidence of user actions depends on the relative effort required to take those actions. Therefore, we observe that roughly (order of magnitude) 100 views "contribute" one like in our linear models, and roughly 10 likes "contribute" a make. The first is not particularly surprising. However, the fact that only 10× likes contribute a make seems to suggest that users are actively seeking things, and have the means and motivation to actually *print* things that they have liked.

Another interesting and intuitive observation is that the number of files has a *negative* effect on makes. This provides evidence for the hypothesis that simpler things (consisting of fewer parts) are more likely to be made.

Sublinearities. Similar relationship between user actions has been observed in other domains [7]. These are also present in our data (Figure 2, exponential-size bucket smoothed), where we find more specifically that $\#Likes \propto \#Makes^{0.70}$ and $\#Views \propto \#Likes^{0.85}$.

Popular vs. generative: likes do not predict remixes. A more surprising finding is that typical measures of general popularity have little relation to whether a thing is remixed or not: (i) makes are, in fact, the worst predictor of number of remixes (also Figure 2 right); and (ii) in fact, the number of remixes is a *bad* predictor of almost everything, *except* of other remixes (Table 1)! This suggests that aspects of a design that make it broadly appealing are distinct from aspects that make it inspiring and, furthermore, agrees with the author's personal experience that following remix links is more useful when looking for ideas, than when looking for utilitarian or fun things to print.

[1]In fact, after the introduction of the Thingiverse Customizer, the rate has picked up even further.

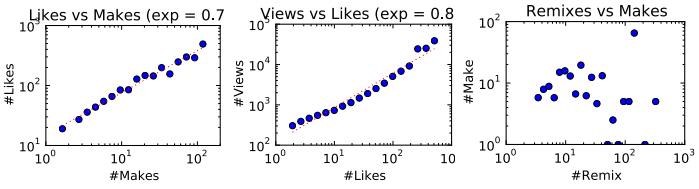

Figure 2: Likes, makes, and remixes.

Interactive visualization. We have also developed an interactive visualization of the thing corpus, accessible at `http://bitquill.net/make/remix`, as a step towards further exploration and understanding of the data at an aggregate level. The visualization is based the excellent D3 Javascript library, with some preprocessing on the back-end to extract relevant aspects from the data. It is under active development and currently focuses on the thing remix graph. We encourage readers to browse the visualization. For example, how is an iPhone case with customized image engravings related to a 3D scan of Stephen Colbert's head, or to the Stanford bunny 3D model?

3. DISCUSSION AND CONCLUSION

Despite the explosive growth and rising importance of 3D printing, to the best of our knowledge there are very few data-driven studies [8] that try to understand it. Our work, which originally stems from one of the authors' involvement in 3D printing, introduces the overall context and dataset to a broader audience, and we identify and highlight observations, including: (i) explosive growth with a clear doubling law, and remixes outpacing general growth; (ii) sublinearity laws in the relationship between user actions; (iii) quantitative evidence for difference between generativity and popularity.

4. REFERENCES

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